X-520-68-76

IONOSPHERIC EFFECTS ON TELEMETRY AND TRACKING SIGNALS FROM ORBITING SPACECRAFT

R. J. Coates
T. S. Golden

March 1968

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

ABSTRACT

Ionosphere characteristics important to space telemetry are discussed. Projections of auroral interference through 1969 are made based on correlation of measurements with solar activity data. Measured results of disturbances at equatorial tracking stations are presented.

CONTENTS

ILLUSTRATIONS

IONOSPHERIC EFFECTS ON TELEMETRY AND TRACKING SIGNALS FROM ORBITING SPACECRAFT

INTRODUCTION

The most heavily used band for space telemetry and tracking has been the 136 to 138 MHz band. This is a natural result of the superiority of VHF solid state spacecraft components. In utilizing the VHF band, spacecraft designers must take into consideration the ionospheric disturbances of 136 MHz signals which are fairly common in certain geographical zones. This paper discusses some of the characteristics of these disturbances.

High ionospheric activity is observed in the auroral zone which passes through Alaska. Another zone of high activity is centered about the magnetic equator which passes through Lima, Peru. Serious disruptions of VHF telemetry, command, and tracking operations are experienced in both of these zones.

AURORAL IONOSPHERIC DISTURBANCES

The Goddard Space Flight Center and the Geophysical Institute of the University of Alaska have been jointly studying the auroral ionospheric disturbances to satellite signals received at the NASA Data Acquisition Station at Fairbanks, Alaska. Satellite signal scintillations have been recorded at 136, 235, 400, and 1700 MHz for a period of over three years. In addition, radio star scintillations have been recorded at 137 and 68 MHz over the same time period.

The observed distributions of peak-to-peak amplitudes of scintillations of 136 MHz satellite signals are shown in Figure 1. The middle curve is the average distribution for the total period from January 1965 through September 1967. The upper curve is the distribution for the month of peak activity, September 1967, and the lower curve is the distribution for the month of lowest activity, December 1965. For most satellites, a peak-to-peak scintillation of 6 db is not a significant problem because it is the same order of magnitude as the signal variations due to the spacecraft antenna pattern. However, when the scintillation is 12 db or higher most telemetry acquisition is degraded. At levels of 18 db of scintillation the telemetry is extremely poor and the data acquisition receiver drops out of lock occasionally. The scintillation levels above 12 db are a serious operational problem to a satellite project. The data presented in Figure 1 shows that for the past 3 years at Fairbanks, Alaska, on the average 25 percent of the satellite data acquisition passes had signal scintillations of 12 db or greater peak-to-peak. During the most disturbed month, 65 percent of the passes had scintillations greater than 12 db.

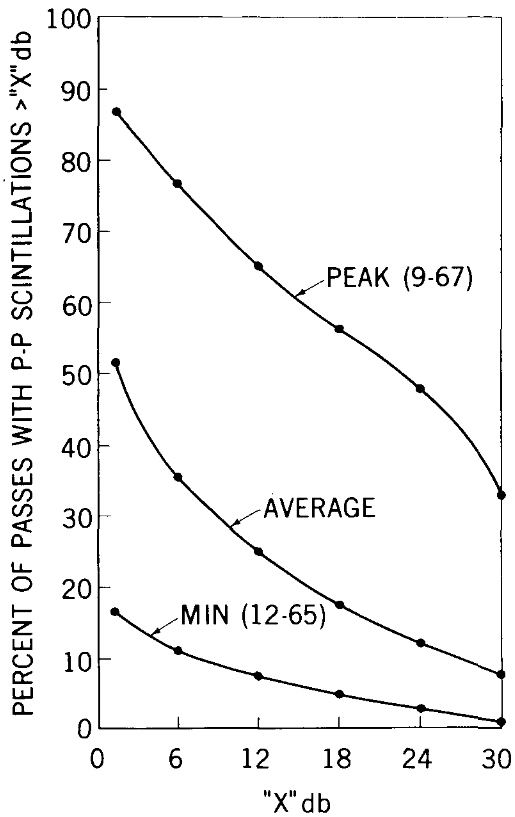

Figure 1. Amplitude Distribution of Peak-to-Peak Scintillation of 136 MHz Satellite Signals Due to Auroral Ionospheric Disturbances

The Geophysical Institute[1],[2] has correlated scintillation with all-sky camera photographs of auroral activity and TV camera images of the sky in the direction of antenna pointing. These comparisons clearly show that the VHF telemetry scintillations are concurrent with visible auroral disturbances. Since visible aurora is known to depend on solar activity, we would expect scintillation also to be dependent upon solar activity. Auroral scintillation and solar activity data collected over the past several years clearly show such a correlation.

Since scintillation levels greater than 12 db are critical to data acquisition, a correlation was made of the number of passes with scintillations greater than 12 db against the monthly mean of the 10.7-cm solar flux as reported by Ottawa[3],[4]. This correlation is shown in Figure 2. This observed correlation can be represented by the equation $P_{12} = 0.41\ (F-48)$ where P_{12} is the percent of 136 MHz satellite passes with peak-to-peak scintillations greater than 12 db and F is the monthly mean value of the 10.7-cm solar flux.

The peak of the solar cycle is expected to be in 1968, however, the present levels of solar activity are very close to the peak values anticipated. Sufficient data is available to extrapolate from current measurements through the remainder of the solar cycle. Our projection, Figure 3, indicates that for the time period between June 1967 and June 1969, the 10.7-cm solar flux mean values will be between 150 and 160 reaching a maximum about mid-1968. The auroral scintillation projection for the same period indicates that on the average between 42 and 46 percent of the passes would have scintillations in excess of 12 db. Occasional periods of very high ionospheric disturbance similar to September 1967 are to be expected during this period.

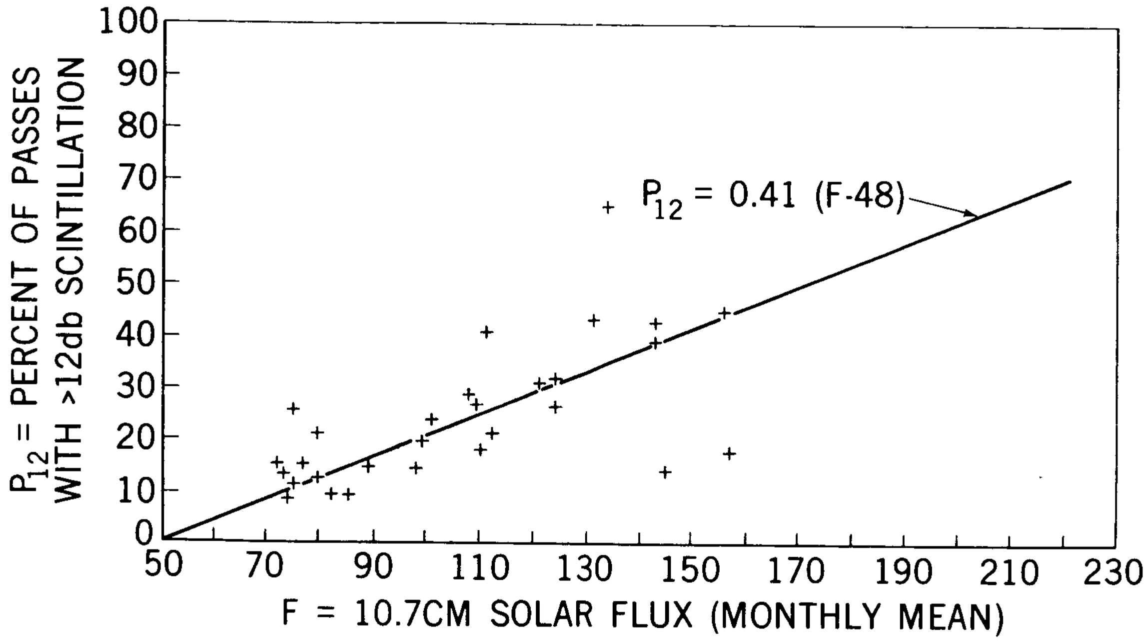

Figure 2. Correlation Between 136 MHz Satellite Signal Scintillations and 10.7-cm Solar Flux

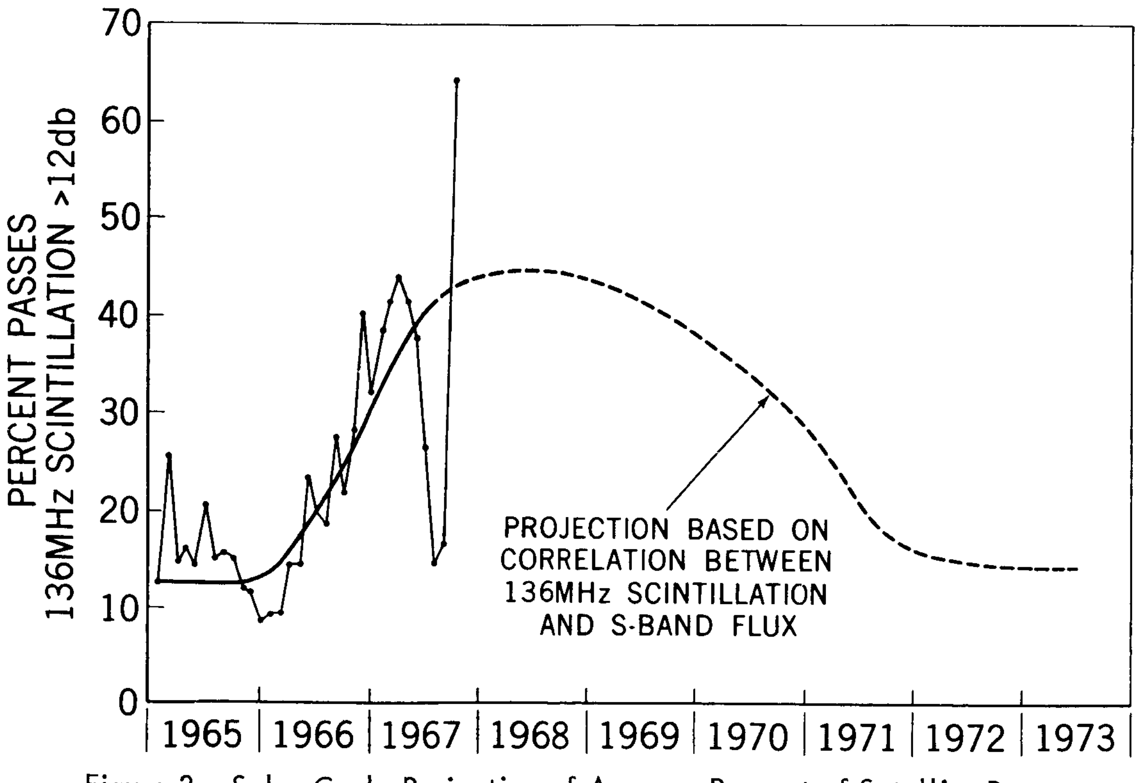

Figure 3. Solar Cycle Projection of Average Percent of Satellite Passes with 136 MHz Signal Scintillations Greater Than 12 db

EQUATORIAL IONOSPHERIC DISTURBANCES

The ionospheric disturbances experienced in the region of the earth's magnetic equator have a much different character than that observed in the auroral zone. The disturbances at the magnetic equator have a very strong diurnal variation. This shows up on the records of the Minitrack system, an interferometer tracking system which measures the angle of arrival of the signal from the spacecraft. The ionospheric disturbance creates considerable scintillation in both amplitude and phase. During the nighttime hours a fairly sizeable number of Minitrack passes are completely destroyed by the ionospheric disturbances. Figure 4, a plot of the percent of lost Minitrack passes for the Lima, Peru, station for the month of March 1967, shows that the percent of Minitrack passes lost as a function of the hour started to increase just after sunset and went up to a maximum of almost 70 percent close to midnight and then dropped down again to negligible amounts shortly after sunrise. The total number of passes that were lost during the month amounted to approximately 14 percent of all passes attempted. Figure 5 presents the average diurnal variation, measured for the 12 month period from July 1966 through June 1967, for stations at Lima, Peru; Quito, Equador; and Santiago, Chile. The highest activity is at Lima which is

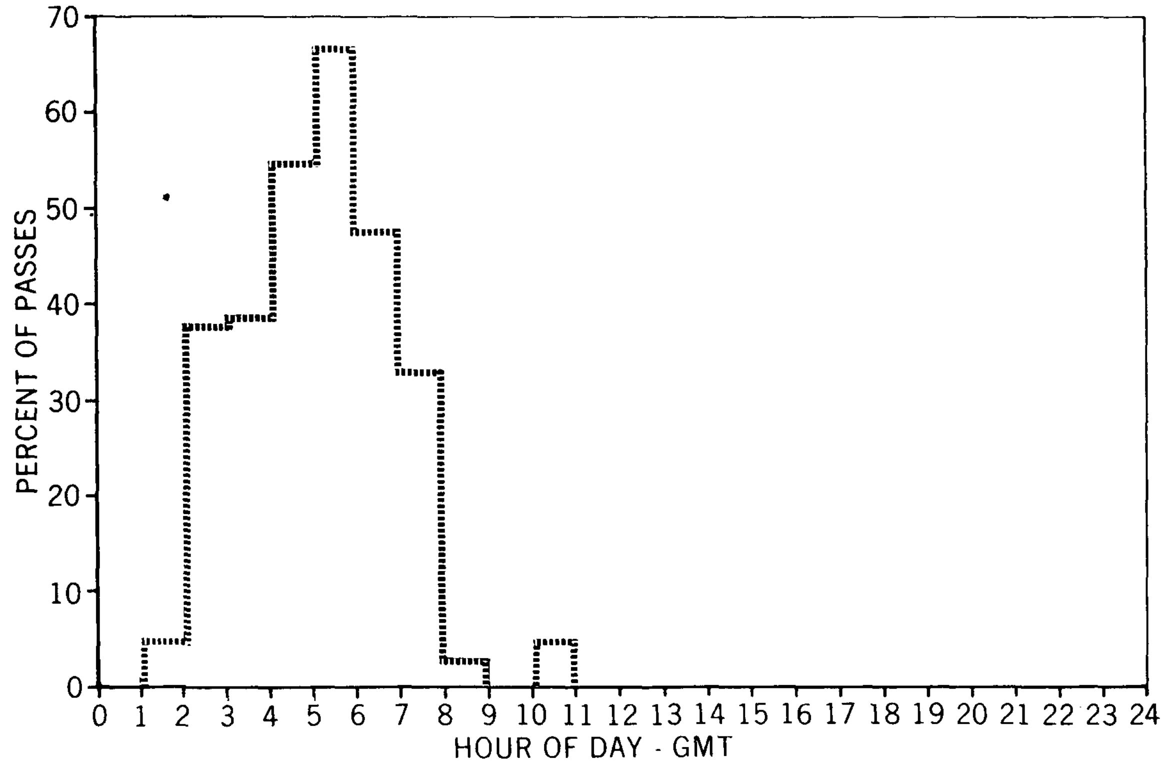

Figure 4. Scheduled Minitrack Passes Missed by Hour of Day for Lima, Peru in March 1967 Due to Propagation Distortion

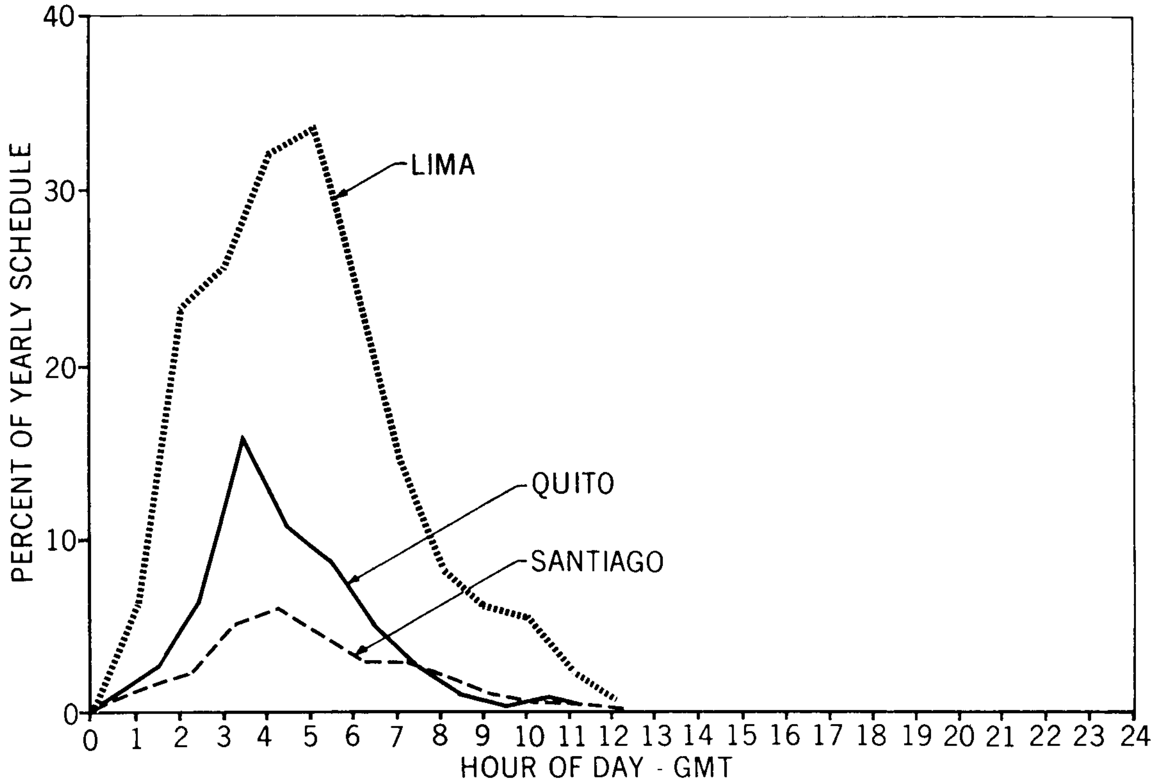

Figure 5. Scheduled Minitrack Passes Missed by Hour of Day During 12 Month Period Due to Propagation Distortion

on the magnetic equator, lesser activity was observed at Quito and Santiago which are respectively North and South of the magnetic equator.

The similarity between the diurnal variation for scintillation and for the spread F ionospheric condition has led some to the conclusion that the disturbance to 136 MHz is related to spread F conditions. However, the seasonal variation of VHF scintillation is not consistent with the spread F seasonal variation. The measured seasonal variations for Lima, Quito, and Santiago are given in Figure 6. The disturbance to 136 MHz signals peaks to a maximum in the spring and then drops to a minimum in the summer, rises to a maximum in the fall, and then drops to a lower minimum in the wintertime.

Equatorial telemetry scintillation effects have not been so exhaustively treated as have auroral effects. However, records of IMP-F from Santiago, Chile, show prolonged scintillation greater than 35 db. Further study is necessary in order to more firmly establish the ionospheric conditions responsible for the equatorial scintillations.

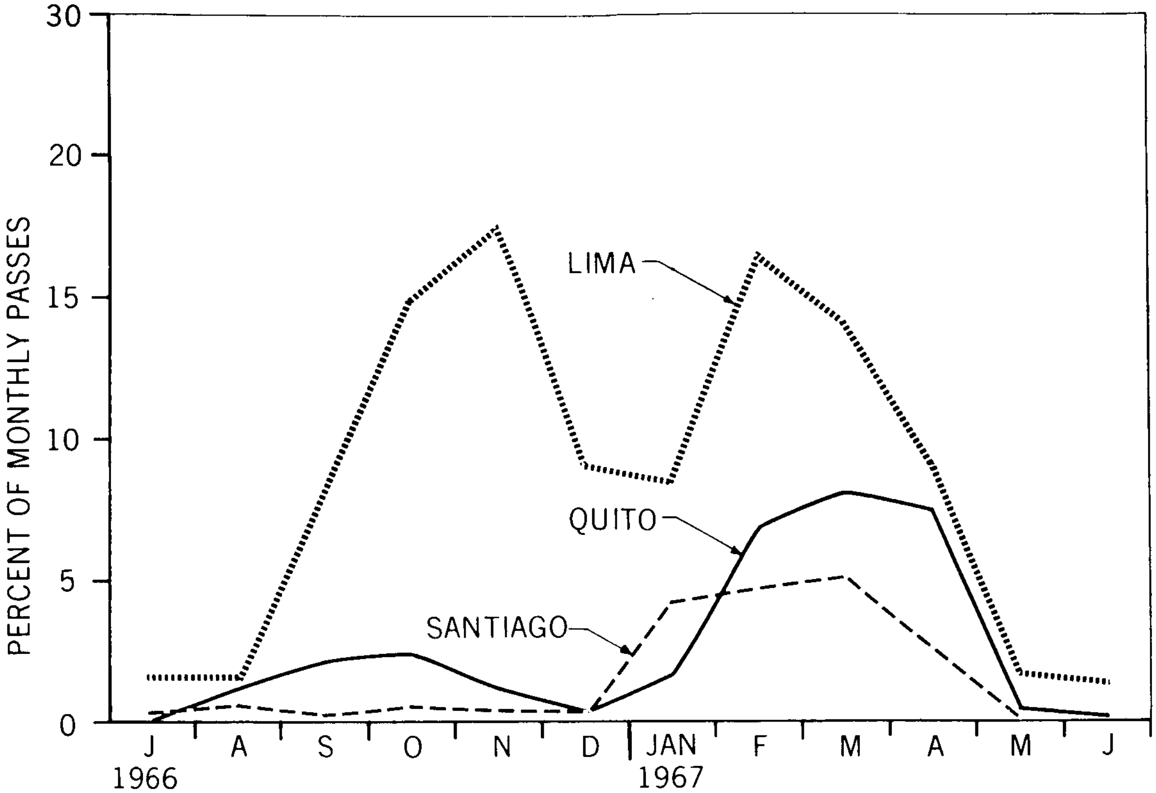

Figure 6. Scheduled Minitrack Passes Missed by Month Due to Propagation Distortion

The Minitrack system measures the angle of arrival with two different sets of interferometer antennas, one oriented North-South and the other oriented East-West. During conditions of ionospheric disturbance, the East-West baseline is much more severely disturbed than the North-South baseline. This is consistent with a model of the ionosphere consisting of densely ionized streams aligned North-South with the magnetic field of the earth.

SYSTEM DESIGN CONSIDERATIONS

The natural question to ask is what can be done to circumvent the degradation due to ionospheric disturbance. Fremouw[1] has shown that the auroral scintillations are due to scattering in the ionosphere and that the optical depth for scattering is inversely proportional to the square of the frequency. Scintillation is thus much less at higher frequencies. This was determined from the analysis of several records of simultaneous observations at multiple frequencies. At a frequency of 1700 MHz, ionospheric scintillations were observed on only two passes out of 1500. Those two passes had scintillations of only 1 db peak-to-peak. Satellites in polar orbits such as the operational weather satellites which make very heavy use of the northern station at Fairbanks, Alaska, must move to the higher frequencies in order to maintain the operational reliability demanded of the mission. Similar considerations of the equatorial ionospheric disturbances lead to the conclusion that higher frequencies should be used when reliable spacecraft tracking, command, and data acquisition are important.

Space diversity is another technique for combating the severe effects of ionospheric disturbance. The interferometer measurements(1) have been used to determine the size of the ionospheric disturbance elements. It has been shown that if 2 antennas are placed at a distance greater than 300 meters, the probability is very high that the scintillations received at the two antennas will not be correlated. Under these conditions, the outputs of the two antennas can be combined to effectively cancel the deep scintillation nulls.

Auroral ionospheric activity is highly variable with time, so another possible technique to reduce the disturbance of telemetry acquisition is to employ a monitoring system which indicates to an operator the disturbance condition of the ionosphere in real time. This permits the operator the freedom to select times for data acquisition to be consistent with minimum levels of ionospheric activity. The most effective real time display for the Fairbanks, Alaska, Data Acquisition Station has been a display of the radio star scintillation monitor. The radio star Cassiopeia is always visible from Alaska. The signal received from an interferometer system located remotely from the station is sent to the station and displayed on a strip chart recorder. The operator can see scintillations on this signal record and is able to determine immediately the amount of ionospheric disturbance that is present.

REFERENCES

(1) Fremouw, E. J., "Radiowave Scattering Structure in the Disturbed Auroral Ionosphere: Some Measured Properties," Geophysical Institute of U. of Alaska Report UAR R-180, Vols. 1 and 2, June 1966.

(2) Zonge, K. L., and E. J. Fremouw, "Aberrations of Radio Signals Traversing the Auroral Ionosphere," Geophysical Institute of U. of Alaska, NASA Contract NAS5-3940 Annual Report, July 1967.

(3) "Solar-Geophysical Data," Institute for Environmental Research Reports FB-259 through 278, ESSA Environmental Data Service, Boulder, Col.; Mar. 1966 - Oct. 1967.

(4) "Solar-Geophysical Data, Descriptive Text and Index," Space Disturbances Lab; ESSA, ITSA; Boulder, Col.; Jan. 1966